5TH INTERNATIONAL CONFERENCE ON NEW DEVELOPMENTS IN PHOTODETECTION 2008
AIX-LES-BAINS, JUNE 2008

ETH Institute for Particle Physics

First Avalanche-diode Camera Test (FACT)

A novel Camera using a G-APD Array for the Observation of very high-energy γ-Rays with Cherenkov Telescopes

I. Braun[1], S.C. Commichau[1], M. Rissi[1], M. Backes[2], A. Biland[1], T. Bretz[3], I. Britvitch[1], H. von Gunten[1], D. Hildebrand[1], D. Kranich[1], E. Lorenz[1], W. Lustermann[1], K. Mannheim[3], D. Neise[2], F. Pauss[1], M. Pohl[4], D. Renker[5], W. Rhode[2], U. Röser[1], U. Straumann[6], G. Viertel[1]

[1]ETH Zurich, Institute for Particle Physics, CH-8093 Zurich, Switzerland; [2]Dortmund University of Technology, D-44221 Dortmund, Germany; [3]University of Würzburg, D-97074 Würzburg, Germany; [4]University of Geneva, CH-1211 Geneva, Switzerland; [5]Paul Scherrer Institut (PSI) Villingen, CH-5232 Villingen, Switzerland; [6]University of Zurich, CH-8057 Zurich, Switzerland

Abstract

The successful operation of large Imaging Air Cherenkov Telescopes (IACTs) has opened a new window of Astronomy by observing very high-energy (VHE) γ-rays (0.1 - 100 TeV), thus probing the "non-thermal" high energy Universe. Impressive new results from galactic and extragalactic sources have been obtained during the past four years with the current experiments (CANGAROO, H.E.S.S., MAGIC and VERITAS), demonstrating that the VHE γ-ray sky is much richer than expected few years ago.
The heart of an IACT is the light detection system: a camera consisting of light concentrators, photo sensors and the associated electronics. A crucial design parameter is the Photon Detection Efficiency (PDE). The recently developed Geiger-mode Avalanche Photo Diode (G-APD) - a novel type of semiconductor photo detector - has an improved PDE of more than a factor of two compared to photomultiplier tubes. This new device thus represents an important step forward to a substantially improved camera. We present a design study of a novel camera using G-APD arrays, which might be installed on the refurbished small telescope (HEGRA CT3) on the MAGIC site in La Palma (Canary Islands, Spain).

Introduction

We are building a G-APD-based prototype camera. The camera will be tested under realistic conditions inside the refurbished HEGRA CT3 telescope (figure 1) or an equivalent mount.

Figure 1: A photomontage of the refurbished HEGRA CT3 telescope with ~13 m^2 mirror area (La Palma, Canary Islands, Spain).

Scientific Prospects

- Test of the first G-APD-equipped imaging camera under realistic weather and background conditions.
- Long-term monitoring of nearby, bright blazars at very high energies [1].
- Search for orbital modulation of the blazar emission due to supermassive black hole binaries.
- Study the statistics of flares and their physical origin.
- Trigger follow-up observations with higher sensitivity IACTs.
- Joint observations with the Whipple monitoring telescope for an extended time coverage.
- Obtain multi-messenger observations together with the IceCube neutrino detector.

G-APDs as Photodetectors for IACTs

G-APDs have several attractive features compared to conventional photomultiplier tubes (PMTs) [2]:

- Higher PDE ($\sim$ 60 %).
- Low operation voltage ($<$ 100 V).
- Very robust (no aging due to starlight, not damaged by daylight when under bias).
- Acceptable timing properties.

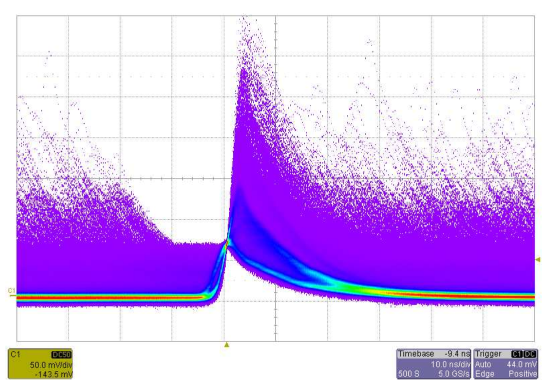

Figure 2: Typical G-APD signal after amplification (dark noise). Horizontal scale: 10 ns/div., vertical scale: 50 mV/div..

The G-APD selected for the camera project (Hamamatsu MPPC S10362-33-100C [3]) has a dimension of 3$\times$3 mm^2 and consists of 900 cells of 100$\times$100 μm^2 size.
Several successful tests were performed in order to evaluate G-APDs as a replacement of PMTs in IACT cameras [4, 5] (see also poster 167, this session [6]).

Camera Layout

The camera layout and design has to meet stringent requirements:

- Water tight, robust and low-weight camera housing to be protected against harsh environmental impacts.
- Modular design for easy replacement of all components.
- Shower images in the TeV-energy range have to be fully contained. To minimize the shower leakage a FoV of 5° is preferred.

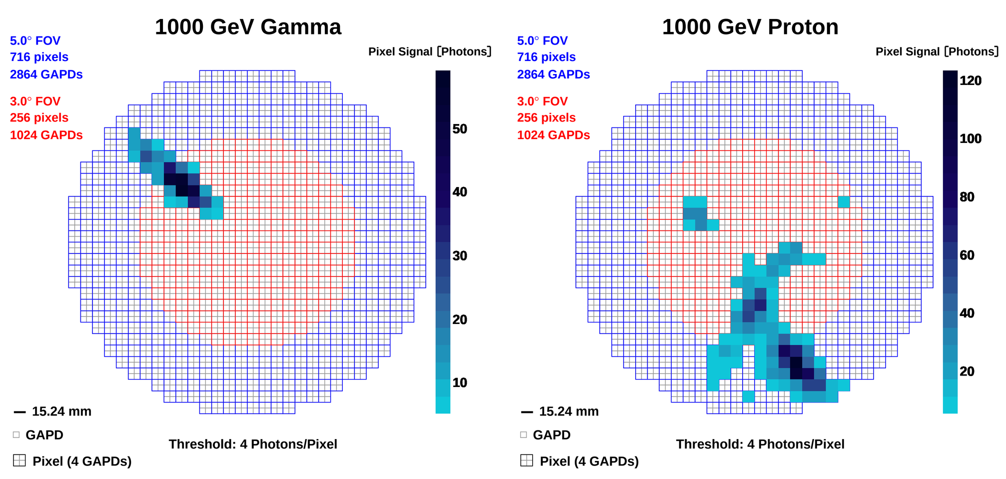

Figure 3: MC simulated 1000 GeV γ-ray (left) and 1000 GeV proton (right) induced showers. The red (blue) area corresponds to a FoV of 3° (5°) respectively. 2$\times$2 G-APDs are grouped to form a pixel (the threshold was set to 4 photons/pixel).

- Flexible trigger logic.
- Each G-APD chip will be equipped with a Winston cone light-guide [7] to maximize the active area.

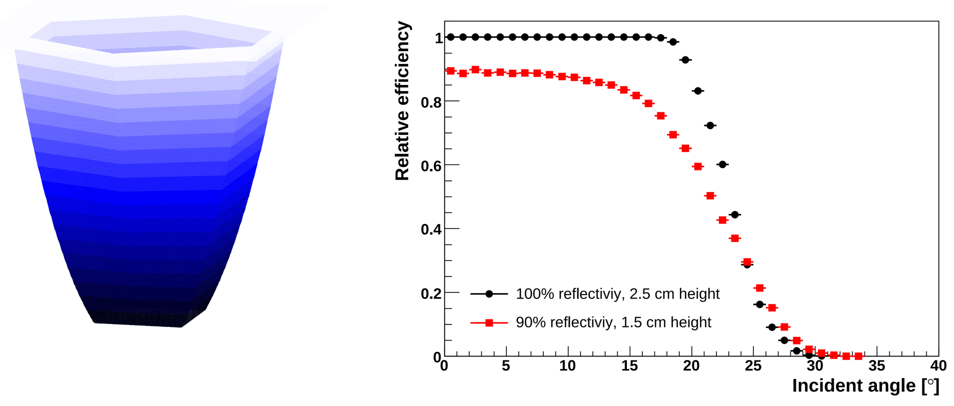

Figure 4: Shape of the Winston cone light-guide (left) and its efficiency for different reflectivities of the coating (right).

Baseline Design

The smallest unit is formed by one pixel (4 G-APDs):

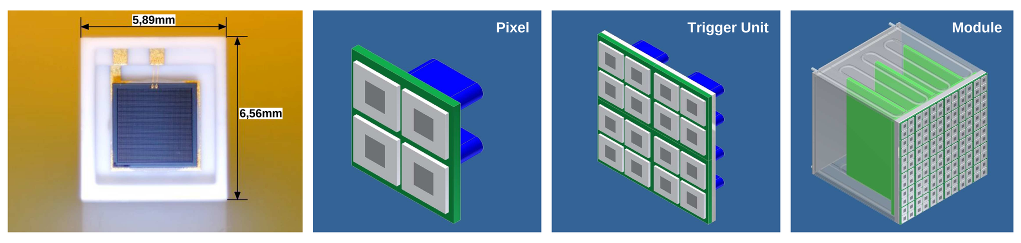

Figure 5: From left to right: the Hamamatsu G-APD (MPPC S10362-33-100C [3]), layout of a pixel (2$\times$2 G-APDs), a unit (16 G-APDs) and a module composed of 6$\times$6 pixels (144 G-APDs).

The camera construction will be done in three stages:

- **Stage 0**: the first module will be mounted on HEGRA CT3 to test the system and to perform measurements of the night sky background and first cosmic ray showers.
- **Stage 1**: assembly of six modules with electronics integrated in the camera housing (3° FoV camera). This setup will allow for sufficient γ/hadron separation to be able to measure the VHE γ-ray emission from the Crab Nebula.
- **Stage 2**: final design (5° FoV camera).

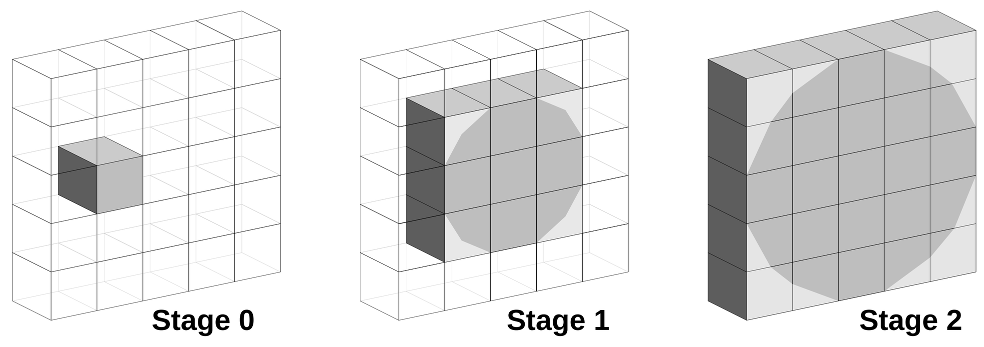

Figure 6: The camera baseline design.

Readout and Data Acquisition System

- Signals of four G-APDs of a camera pixel will be linearly added and amplified by dedicated front-end electronics.
- The analog signals will be sampled at 2 GHz in order to provide the time resolution required for the detection of Cherenkov light and the separation of γ-ray and hadron induced showers.
- The Domino Ring Sampling (DRS) chip, developed at PSI [8], will be used for the DAQ.

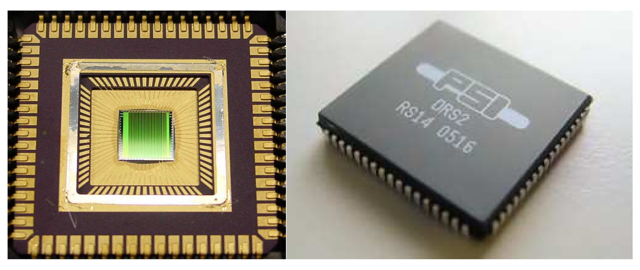

Figure 7: The DRS chip without and with ceramic package.

- The DRS provides 12 analog pipelines, each of which consists of an array of 1024 capacitive sampling cells (arranged in a ring-buffer).
- Each analog pipeline is read out at 40 MHz with an external 12 bit flash analog-to-digital converter (FADC).
- A DRS-based DAQ was already used for the detection of Cherenkov light with G-APDs [4, 5] (see also poster 167, this session [6]).
- The trigger decision will be based on discriminating the signals of each pixel and generating majority information for the trigger units. A second level trigger will process the majority information to produce a trigger decision.

References

[1] F. Goebel et al., *Long term monitoring of bright TeV Blazars with the MAGIC telescope*, 30th International Cosmic Ray Conference, Mérida, México, 2007, arXiv:0709.2032v1 [astro-ph].

[2] D. Renker, *New trends on photodetectors*, Nucl. Instr. and Meth. in Phys. Res. A 571 (2007).

[3] MPPC data sheet of Hamamatsu Photonics: http://sales.hamamatsu.com/assets/pdf/catsandguides/mppc_kapd0002e03.pdf.

[4] A. Biland et al., *First detection of Cherenkov light from cosmic-particle-induced air showers by Geiger-mode avalanche photodiodes*, Nucl. Instr. and Meth. in Phys. Res. A 581 (2007) 143-146.

[5] A.N. Otte et al., *Detection of Cherenkov light from air showers with Geiger-APDs*, 30th International Cosmic Ray Conference, Mérida, México, 2007, arXiv:0712.1592v1 [astro-ph].

[6] N. Otte et al., *Detection of Cherenkov Light from Air Showers with Geiger APDs: Recents Tests and Future Perspectives*, this conference.

[7] D. Jenkins and R. Winston, *Integral Design method for non-imaging concentrators*, J. Opt. Soc. Am. A/Vol. 13, No. 10, October 1996.

[8] S. Ritt, *Design and Performance of the 5 GHz Waveform Digitizing Chip DRS3*, Nucl. Science Symposium Conference Report 4 (2007) 2485-2488, NSS '07, IEEE.

Corresponding authors: sebastian.commichau@phys.ethz.ch, michael.rissi@gmail.com